Report No. CG-D-30-95

RISK MANAGEMENT MODEL OF IIP OPERATIONS

Annex K of Cost and Operational Effectiveness Analysis for Selected International Ice Patrol Mission Alternatives

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FINAL REPORT

JUNE 1995

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Prepared for:

U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, Connecticut 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering, Logistics, and Development
Washington, DC 20593-0001

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Technical Report Documentation Page

1. Report No. CG-D-30-95	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle RISK MANAGEMENT MODEL OF IIP OPERATIONS Cost and Operational Effectiveness Analysis for Selected International Ice Patrol Mission Alternatives, Annex K		5. Report Date May, 1995
		6. Performing Organization Code
7. Author(s) Armacost, Robert L. and Pet-Edwards, Julia		8. Performing Organization Report No. R&DC 29/95
9. Performing Organization Name and Address EER Systems Corporation 1593 Spring Hill Road Vienna, VA 22182		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTCG39-94-C-E00085
12. Sponsoring Agency Name and Address U.S. Department of Transportation U.S. Coast Guard Office of Engineering, Logistics, and Development Washington, DC 20593-0001	United States Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6069	13. Type of Report and Period Covered **Final Report** **July, 1994 to June, 1995**
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report is Interim Report Volume 11 for the Cost and Operational Effectiveness Analysis for Ice Patrol Mission Analysis Study. The International Ice Patrol uses a set of integrated models with interactive analysis to evaluate reported iceberg sighting information and estimate the current positions of all known icebergs that may impact North Atlantic shipping. The objective of this model is to provide timely, accurate, and relevant information to the mariner regarding the location of icebergs. In order to determine whether existing data and models are adequate, there is a need for a means to evaluate the risk and uncertainty associated with current IIP operations. A risk analysis depends on an uncertainty analysis which propagates the uncertainty in input elements (iceberg detection/classification, environmental factors, drift and deterioration models, resighting procedures, and numerous policies) to characterize the uncertainty in the output (the location of the LAKI). This report provides a foundation for risk analysis and develops an approach for modeling risk and uncertainty associated with IIP operations. Based on the sensitivity analyses of the drift and deterioration models, it is clear that an analytical representation for output uncertainty as a function of input uncertainty is not feasible. Instead, a promising approach is the use of Monte Carlo simulation utilizing the "What-If" DMPS model at IIP.

17. Key Words International Ice Patrol Icebergs Risk Uncertainty	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service Springfield, VA 22161

19. Security Classif. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. No. of Pages 18	22. Price

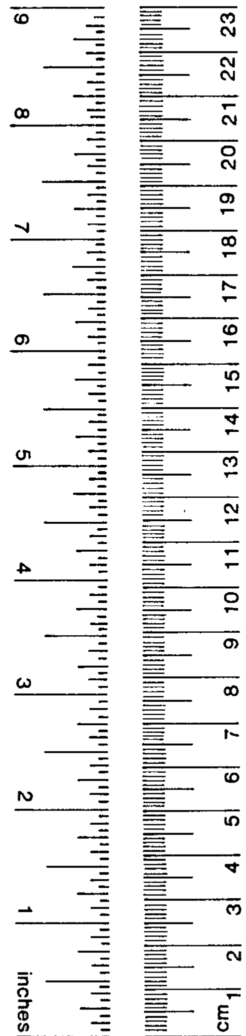
Form DOT F 1700.7 (8/72)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

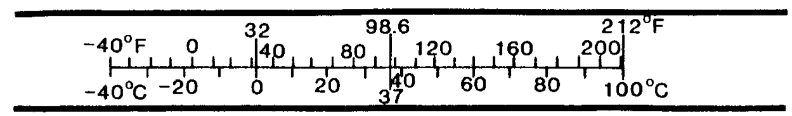
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



RISK MANAGEMENT MODEL OF IIP OPERATIONS

ABSTRACT

The International Ice Patrol uses a set of integrated models with interactive analysis to evaluate reported iceberg sighting information and estimate the current positions of all known icebergs that may impact North Atlantic shipping. The objective of this model is to provide timely, accurate, and relevant information to the mariner regarding the location of icebergs. In order to determine whether existing data and models are adequate, there is a need for a means to evaluate the risk and uncertainty associated with current IIP operations. A risk analysis depends on an uncertainty analysis which propagates the uncertainty in input elements (iceberg detection/classification, environmental factors, drift and deterioration models, resighting procedures, and numerous policies) to characterize the uncertainty in the output (the location of the LAKI). This report provides a foundation for risk analysis and develops an approach for modeling risk and uncertainty associated with IIP operations. Based on the sensitivity analyses of the drift and deterioration models, it is clear that an analytical representation for output uncertainty as a function of input uncertainty is not feasible. Instead, a promising approach is the use of Monte Carlo simulation utilizing the "What-If" DMPS model at IIP.

INTRODUCTION

Objective.

The selected modeling alternatives for Phase II of the Cost and Operational Effectiveness Analysis included conducting a detailed sensitivity analysis of the system and developing an approach to characterize the risk posture for the IIP (Armacost, 1994). The detailed sensitivity analysis is addressed in other reports. The purpose of this report is to review risk concepts and to develop a model approach to characterize risk and uncertainty for the IIP operations. The analysis identifies potential risk and uncertainty measures that can be used to evaluate IIP operations and proposes appropriate methodologies to do so.

Background.

The IIP operationalizes the IIP mission as *determining the Limits of All Known Ice along the southeastern, southern, and southwestern edge of the ice region and publishing that information to mariners in a timely fashion.* This mission involves data and information acquisition, processing, and distribution--finding out where the ice danger

is for trans-Atlantic shipping and telling the mariner so as to prevent ship-iceberg collisions. The primary products of the IIP are the 0000Z and 1200Z Ice Bulletins and the 1200Z Facsimile Ice Chart that depict the Limits of All Known Ice (LAKI) and positional information on selected icebergs and radar targets. Figure 1 provides a context diagram illustrating these information processing activities. The key data inputs are the iceberg and radar target sightings/reports, and selected environmental data which permits iceberg drift and deterioration to be modeled. The drift and deterioration models and the policies/parameters associated with their operation combine to provide prognosis (predicted) positions of icebergs which determine the LAKI.

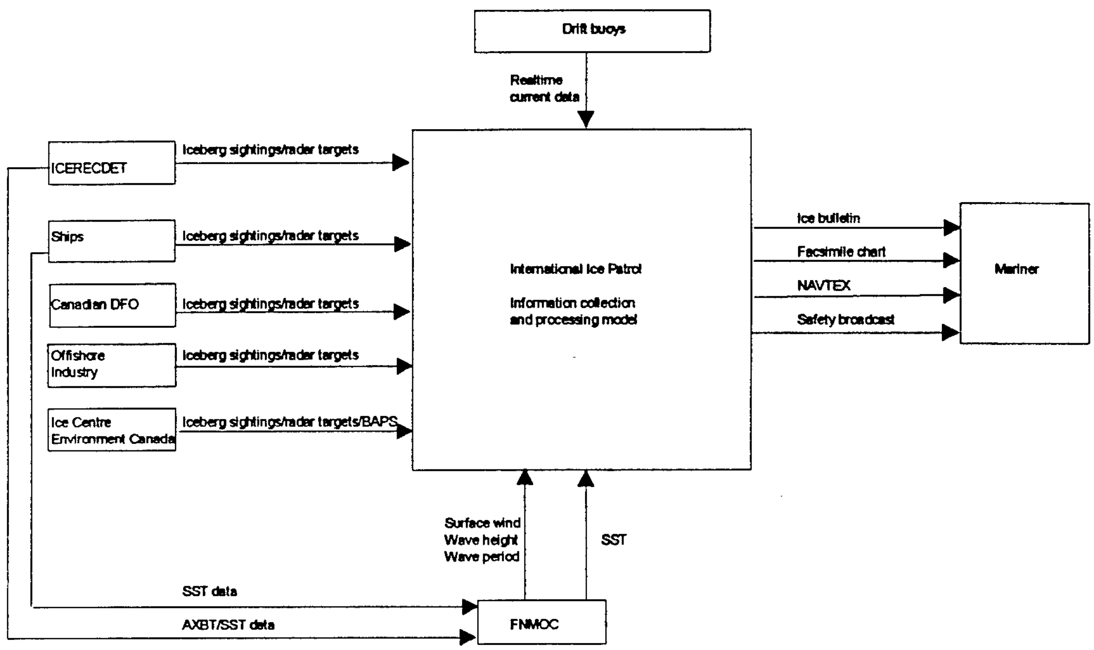


Figure 1. IIP Information Processing Context Model.

The IIP effectively captures available data on iceberg and radar target sightings from other organizations as well as from IIP Ice Reconnaissance Detachment flights. Because of the importance of high quality information along the Limits of All Known Ice, the IIP Ice Reconnaissance Detachment (ICERECDET) conducts bi-weekly surveillance flights from St. John's, Newfoundland that concentrate on providing information on icebergs and radar targets in the area defining the LAKI. The primary source of environmental data is the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC). IIP receives surface wind, wave height, and wave period data twice a day and sea surface temperature (SST) data once each day. In addition, realtime current data from IIP deployed drift buoys is incorporated on a regular basis to temporarily modify the (geostrophic) Labrador Current data file. The surface wind, iceberg position, estimated iceberg size, and geostrophic current are used in the iceberg drift model. A separate iceberg deterioration model uses the iceberg position, iceberg size, SST, and wave height and period data.

In addition to a sensitivity analysis of these models, it would be extremely valuable to be able to estimate the risk associated with the use of the models with current data inputs and policies. The ability to assess this risk would facilitate evaluation of the need for improved input data or modification of operational policies.

RISK AND UNCERTAINTY

Defining Risk, Uncertainty and Risk Analysis.

A comprehensive analysis of the modeling and policy risks incurred by the International Ice Patrol is an essential part of mission analysis. The sources of uncertainty in the models used, the potential introduction of errors (either judgmental or measurement), and the approximations or simplifying assumptions all can impact the accuracy of the reports provided by the IIP. Inaccuracy in the specification of LAKI could potentially lead to an increased risk of vessel collision with an iceberg outside of the published LAKI and may have both financial and political implications to the U.S. Coast Guard.

In general, a consideration of risk during policy formulation is receiving considerably more attention today than in the past. Despite this attention, there still does not seem to be full agreement on a precise meaning of risk. Some of the earlier definitions of risk made a distinction between risk and uncertainty. Early decision analysts defined risk to encompass those situations where probabilities are known and uncertainty to encompass situations where probabilities are unknown (Luce and Raiffa, 1957). This distinction is still being used by some researchers (USWRC, 1980; Lindley, 1985). Some contemporary definitions of risk include uncertainty as an integral part of the risk definition. Dictionaries define risk to be "a factor, element, or course involving uncertain danger; hazard." (American Heritage, 1971). Morgan (1981a,b) describes risk in terms of an exposure process and an effects process. Morgan and Henrion (1993) define risk as an exposure to a chance of injury or loss. Kaplan and Garrick (1981) describe risk as the probability of loss or injury and the degree of probability of such loss. Uncertainty is defined as the condition of being in doubt due to lack of or questionable information. Kaplan and Garrick (1981) illustrated the distinction between risk and uncertainty using the following example:

> "Suppose a rich relative had just died and named you a sole heir. The auditors are totaling up his assets. Until that is done you are not sure how much you will get after estate taxes. It may be $1 million or $2 million. You would then certainly say you were in a state of uncertainty, but you would hardly say that you are facing risk."

Most contemporary researchers seem to agree that risk involves both uncertainty and the notion of some type of potential damage.

The process of risk analysis involves both the quantification of risk and the determination of risk acceptability. Lowrance (1976) describes risk as a measure of the probability and severity of adverse effects and defines safety as the degree to which risks are judged to be acceptable. He notes that two activities are required in determining the acceptability of risk. Measuring risk is an objective, although probabilistic, activity; while judging acceptability involves active personal and social value judgments. Morgan (1981a,b) breaks the risk analysis process into three steps: (1) risk assessment (where risk magnitudes are measured, (2) risk abatement (determining means of regulating or limiting risk levels), and (3) risk management (determining what level of risk is acceptable and who is responsible).

Quantifying Risk in Policy Models.

Using the Kaplan and Garrick (1981) definition of risk, we find that risk measurement should involve the quantification of uncertainty and the potential damage. They suggest that the following three questions should be answered: (1) What can happen? (i.e., what can go wrong?), (2) How likely is it that it will happen?, and (3) If it does happen, what are the consequences? One approach to this type of analysis is to perform an exhaustive analysis of possible failure modes coupled with the probability of sequential component failures coupled with the consequences. Rowe (1977) describes the process as one of defining the causal events, their outcomes, exposure pathways, and potential consequences; and then associating probabilities with each of these factors.

The use of probabilities or probability distributions is the best known and most used means for quantifying uncertainty within a policy model. In cases where the quantification of probabilities may not be appropriate, sensitivity analysis provides another means of assessing the impacts of uncertain or assumed values. Uncertainty analysis (which is an integral part of risk analysis) examines the total uncertainty induced in the output of the policy model by quantifying the uncertainties in the inputs to the model and the quantities within the model itself. It also considers the relative importance of all sources of uncertainty in terms of their contribution to the total uncertainty.

It is useful to examine the types of quantities that enter into a policy model and what role they play in the analysis. These quantities can be broadly classified as empirical parameters, defined constants, decision variables, value parameters, index variables, model domain parameters, and outcomes (Morgan and Henrion, 1993). In general, defined constants are certain by definition (e.g., the number of hours in a day, the specifications of the radar used). Decision variables are quantities over which the decision maker has direct control (e.g., the type of radar used, the size of the assumed error circle, percent of melt after which an iceberg is deleted, the number of lines used to specify LAKI). Value parameters represent the preferences of the decision maker (e.g., assumed iceberg size for radar targets). Although defined constants, decision variables, and value parameters may affect the risk in a policy model, it is generally not appropriate to model them through the

use of probability distributions. Their impact on Coast Guard/IIP risk is more appropriately evaluated through sensitivity analysis.

Empirical quantities include the measurable properties of the system being modeled (e.g., the wind velocity, and the local wind direction). Uncertainties in empirical quantities are often represented through the use of probability distribution functions. Index variables are used to classify the location of an entity in time or space (e.g., longitude and latitude, four size classes of an iceberg, the two shape classes of an iceberg). Model domain parameters specify the domain or scope of the system being modeled and generally specify the range and increments of the index variables (e.g., area of responsibility of the IIP, the time increment used in updating the drift and melt models, the range of the length of an iceberg that makes up a particular iceberg size class). The outcomes of a policy model are the outputs that are used to develop the operational policy (e.g., the position, size, and shape of the limit-setting icebergs that define LAKI). Uncertainties introduced through the defined constants, decision variables, value parameters, empirical quantities, index variables, and model domain parameters impact the accuracy of the outcomes of the policy model.

Morgan and Henrion (1993) state that "uncertainty in empirical quantities ... generally constitute the majority of quantities in models for policy and risk analysis." They proceed to classify the sources of uncertainty in empirical quantities as follows:

- statistical variation,
- systematic error and subjective judgment,
- linguistic imprecision,
- variability,
- unpredictability,
- disagreement, and
- approximation.

The risk and uncertainty introduced into the policy model used by the Coast Guard/IIP originates from a significant number of quantities that are not empirical in nature. However, we have found that the preceding classification is useful for the other quantities (e.g., decision variables, model domain parameters) as well. Each of these sources is briefly described below.

Statistical variation is the uncertainty that comes from random errors when taking direct measurements of a quantity. Variations between observations may arise due to imperfections in the measuring instrument and/or observational technique. For example, local wind velocity, local wind direction, observed position, and geostrophic current are all subject to statistical variation.

Systematic error is generally defined as the difference between the true value of a quantity and the value to which the mean of the observations of the quantity converges. Systematic errors are introduced through biases in the measuring instruments or

experimental procedures. They can occur due to imprecise calibration or biased subjective estimates on the part of observers. Systematic errors may be introduced, for example, in the classification of iceberg size if the observer consistently wishes to err on the high side.

Linguistic imprecision occurs with quantities the have imprecise language. This source of uncertainty often occurs when we try to classify items into categories based on characteristics measured on a continuous scale. For example, there are two types of icebergs defined--tabular and non-tabular (or pinnacled). The distinction between the two types can be quite fuzzy. In a similar regard, the classification of the size of icebergs into growler (less than 15m in length), small (15-60m in length), medium (60-122m in length), and large (over 122m in length) may be subject to linguistic imprecision if the observer cannot make the distinction among the sizes.

A source of uncertainty may also be due to the variability of a quantity. Some quantities may vary over time and space and should be treated as frequency distributions. The uncertainty about the frequency distribution may be one source of error; another would be treating a variable quantity as deterministic within the policy model. An example of the latter is the geometry of the iceberg which is a function of the iceberg size and shape. For a given iceberg size and shape, the geometry of the iceberg is treated as a constant in the drift model. However, since the length of an iceberg within a size classification varies, so should its shape.

Unpredictability may constitute another source of uncertainty. It may occur due to inherent randomness (a type of randomness that cannot be reduced) or due to modeling or computational limitations. A lack of a scientific body of knowledge to support or validate a model can lead to unpredictability. For example, the calving mechanism in iceberg deterioration is recognized as a major component, yet is not modeled due to a lack of knowledge about the exact mechanism and the absence of data. In addition, the use of particular increments for the index variables in a policy model may also lead to unpredictability, particularly if the specification of these increments is due to computational limitations. The drift model consists of four partial differential equations and is solved using a fourth order Runge-Kutta integration technique. The step-size for the numerical integration may introduce uncertainty into the model. In addition, the position of each iceberg is "drifted" for twelve hours before new inputs (e.g., wind and size estimates) are used. This can result in uncertainty due to unpredictability. The melt model is also updated every 12 hours due to data collection limitations and this can also can introduce uncertainty.

Another source of uncertainty may be disagreement among experts. There may be more than one theory or model that might be used in policy analysis and experts may not agree on which one is the most appropriate. It has been suggested by some experts that the present local wind driven current model used in the iceberg drift model should be replaced, which means that the current model may introduce error in the analysis. In other situations, a quantity in a model may be given by the opinion of informed experts and these experts may not agree. Both types of disagreement can introduce uncertainty into

the model. The policy model used by the IIP does not require the consensus of a group of experts; however, experts are used to interpret the radar target and resighting information. If two observers were to interpret the same information on a resighting of an iceberg, they may or may not agree as to which iceberg has been resighted or whether the sighting is a new iceberg.

A final source of uncertainty is the use of approximations in the policy model. Since models are always simplifications of reality, approximations are frequently used. One such approximation is directly related to the model's assumed temporal and spatial domain parameters. Determination of the appropriate resolution for index variables can be problematic. As indicated earlier, the size of an iceberg is approximated by four different size classes rather than performing the computations in the melt and drift models for iceberg lengths on a continuous scale.

RISK ANALYSIS MODEL APPROACH FOR IIP OPERATIONS

The preceding discussion of risk analysis used IIP operations as a context for applying the various definitions and explaining risk and uncertainty concepts. In this analysis, we focus on the approaches for quantifying risk and do not address risk acceptability. Quantification of risk involves quantification of uncertainty and identifying the potential damage that can occur. Kaplan and Garrick (1981) pose three questions that assist in risk quantification: (1) What can happen? (i.e., what can go wrong?), (2) How likely is it that it will happen?, and (3) If it does happen, what are the consequences? Questions 1 and 2 characterize uncertainty and questions 1 and 3 characterize the damage. For IIP operations, we examine the damage questions first.

Risk Quantification: *Damage*.

In meeting its mission objective, the IIP publishes information that describes the Limits of All Known Ice (LAKI). The information should be accurate and be timely. However, this information is simply a statement of what the IIP knows. It is not a statement of actual iceberg conditions. It should be a 100% confidence statement about Coast Guard/IIP knowledge. It also is a confidence statement about the location of icebergs, but the *confidence level is **unknown***. In practice, despite repeated cautions about the possibility of encountering an iceberg outside of the LAKI, the mariner will typically erroneously assume that the published LAKI is a 100% confidence statement about the location of icebergs.

From the Coast Guard/IIP perspective, an adverse event that may lead to damage (in a risk sense) is the actual location of an iceberg outside of the LAKI and its sighting by a vessel, or worse yet, being involved in a collision with a vessel. The potential adverse effects associated with these events include loss of Coast Guard/IIP credibility, physical damage to vessels, injury and/or loss of life, environmental damage, lawsuit for damages, and increased shipping costs due to the necessity to give the LAKI a "wider berth." The

"external encounter" with an iceberg outside of the LAKI answers question 1 and the various adverse effects characterize the damage and answer question 3. In order to make progress in the risk analysis, it is necessary to answer questions 2: how likely is an external encounter? This leads to an uncertainty analysis, which for the IIP operations, is the heart of the risk analysis.

Risk Quantification: ***Uncertainty Analysis*.**

As discussed above, uncertainty analysis examines the total uncertainty induced in the output of the model by quantifying the uncertainties in the inputs to the model and the quantities within the model itself. It also considers the relative importance of all sources of uncertainty in terms of their contribution to the total uncertainty. The uncertainty in the output involves whether the LAKI in fact contains all icebergs. Ideally, the probability that an iceberg is encountered outside of the LAKI is equal to zero. Absent perfect information, we desire that probability to be as low as possible. Therefore, a reasonable objective for the IIP operations is to minimize the probability that an iceberg will be encountered outside of the LAKI. An obvious solution is to permanently inscribe the LAKI at the equator. However, there is a clear tradeoff between the location of the LAKI and the additional cost to shipping even though this tradeoff is not made explicit in any way.

There are two general ways in which an external encounter can occur: a failure to detect and classify an iceberg (while inside the LAKI and then drifts outside of the LAKI), or a modeling error that may involve any of the sources of uncertainty defined above. These are illustrated in Figure 2.

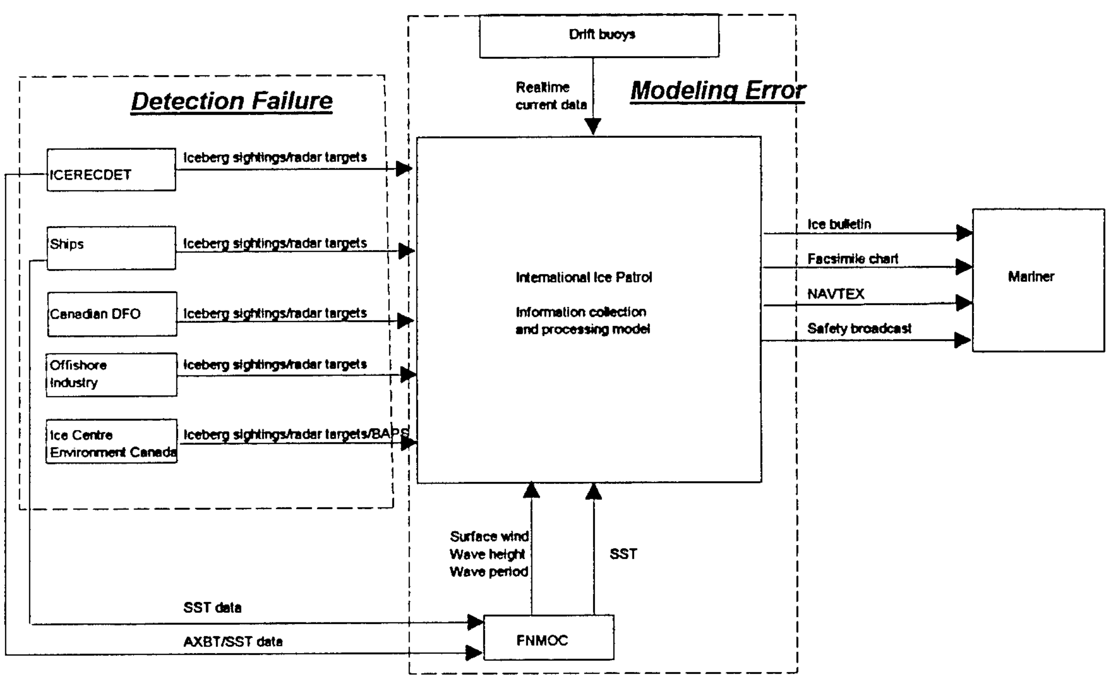


Figure 2. Error sources for external encounter..

To get a better feel for the various factors and their influence on determining the final outcome, these concepts are represented in an influence diagram in Figure 3. This provides additional information on how the various model inputs influence other components in the model and provide a means for propagating uncertainty to the final output, namely, the LAKI. In the influence diagram, the ovals represent activities that have a probabilistic element and the rectangles with rounded corners represent policies and decision actions that may introduce uncertainty. It is important to realize that an influence diagram is not a flow chart. For example, the resight analysis uses the current position of icebergs determined by the drift model. However, the locations do not influence how that resight is conducted. With an influence diagram, it is assumed that knowledge is passed to all other elements that require the knowledge (often shown by a dashed line, but omitted here to simplify the diagram).

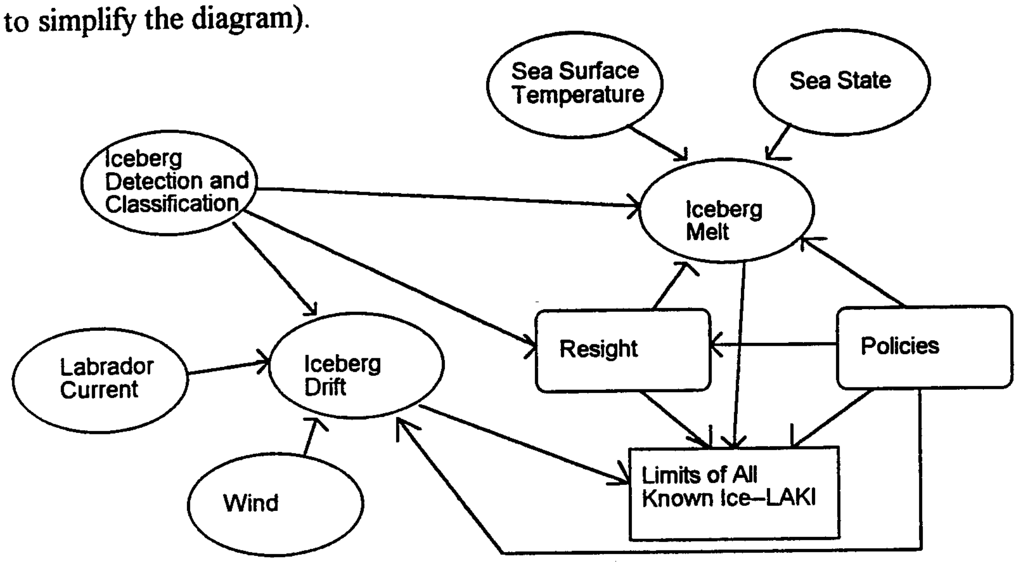


Figure 3. IIP Process Influence Diagram.

The major elements in the IIP operations model include iceberg detection/ classification, iceberg drift, iceberg melt, and resight analysis procedures. The results of these submodels are synthesized to determine the LAKI. In order to identify the sources of uncertainty, it is necessary to develop more refined submodels.

Detection and Classification.

The essential starting point for the IIP operations is the detection and classification of icebergs. A simple influence diagram illustrating the important elements of detection and classification is represented in Figure 4. Further refinement is possible. For example, in addition to weather (visibility) and sea state (radar reflectivity), Coast Guard Detection and Classification is also influenced by skill of the on board operators, iceberg density, state of repair/adjustment of the radars and other factors as well. For purposes of quantifying uncertainty, it will be easier to deal with the model at this level. Experimental results using radar and visual observation with ground truth observations have permitted

estimation of the probability of detection and classification of icebergs using Coast Guard resources (Armacost, 1995a). Because these results were based on radar observations, weather did not affect (influence) the PODI estimation. However, the PODI is dependent on sea state and the results are limited by the observed sea states. Therefore, obtaining meaningful probability distributions and being able to explicitly determine the dependencies and interrelationships will be very difficult.

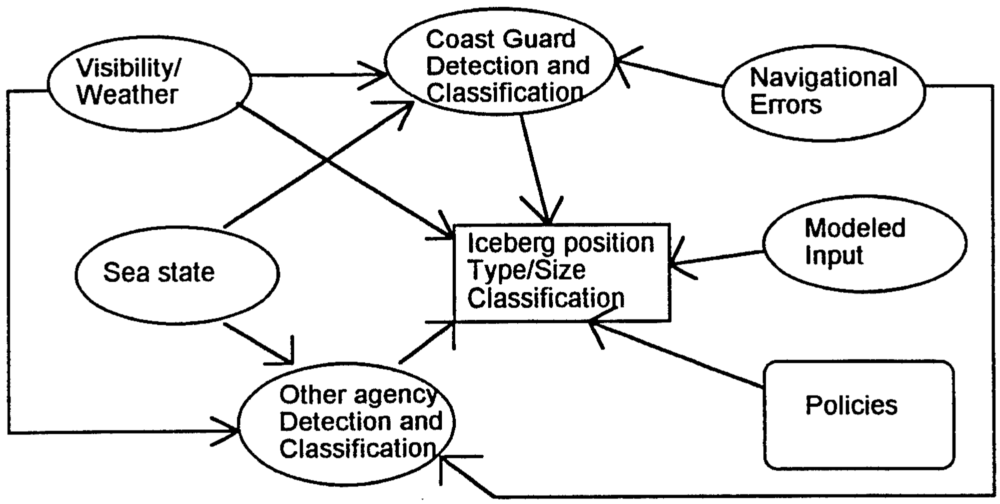


Figure 4. Detection/Classification Influence Diagram.

Iceberg Drift.

A drift model influence diagram is included in Figure 5. Clearly the key starting point is the previous estimated position of the iceberg. Any uncertainty in this position will be propagated through the drift model.

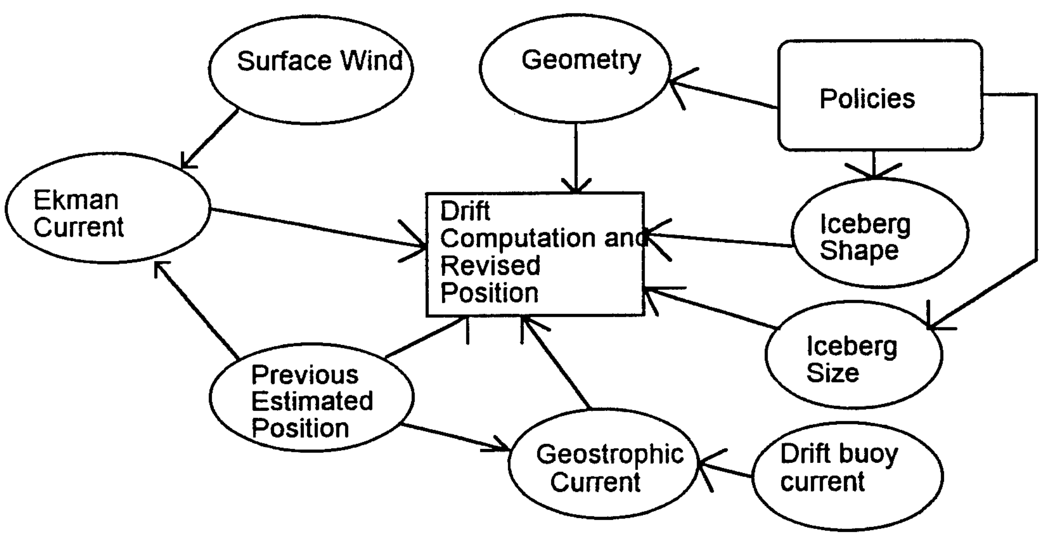


Figure 5. IIP Drift Model Influence Diagram.

In order to quantify the uncertainty, it is important to be able to identify the types of uncertainty that may be present for each source of uncertainty. The discussion of the sources of uncertainty above used numerous examples from IIP operations. Figure 6 suggests particular types of uncertainty for the various sources in the iceberg drift model. A sensitivity analysis of certain parameters is conducted in Armacost (1995c).

	Statistical Variation	Systematic Error/Bias	Subjective Judgment	Linguistic Imprecision	Variability due to sample	Lack of Scientific Knowledge	Approximations
Local wind velocity	X	X					X
Local wind direction	X	X					X
Position (observed)	X	X	X				X
Position (drifted)	X	X	X				X
Geostrophic current	X	X	X			X	X
Iceberg size	X	X	X	X			X
Iceberg shape	X	X	X				X
Geometry							
Surface area	X	X	X		X	X	X
Underwater areas	X	X	X		X	X	X
Ekman current	X	X				X	X

Figure 6. IIP Drift Model Sources of Uncertainty.

Iceberg Deterioration.

The influence diagram for the iceberg deterioration model is included in Figure 7. The deterioration model is straightforward in determining the reduction in waterline length and the new melt state. However, certain errors and uncertainties are not easily carried through the model analytically. For example, misclassification errors due to incorrect size classifications can only be examined by a sensitivity analysis. Similarly, uncertainty in positions results in selecting the incorrect sea state and sea surface temperature, even if those data were 100% accurate.

Policies.

The concept of "policies" appears in all of the above influence diagrams. These incorporate the various assumptions that are made, some of which were referred to in the description of the sources of uncertainty. These include elements such as the number of categories of icebergs, the underwater profile of icebergs, approximations used in constructing the analytic models, classification criteria for radar targets, assumed iceberg size for unclassified icebergs, estimated positional error circle and positional error growth,

and similar factors. Also included as policies are factors such as resighting procedures, size reclassification on resighting, and construction criteria for the LAKI. Most of these can not be represented as probability distributions and require another approach to estimate and then propagate the uncertainty induced by their values.

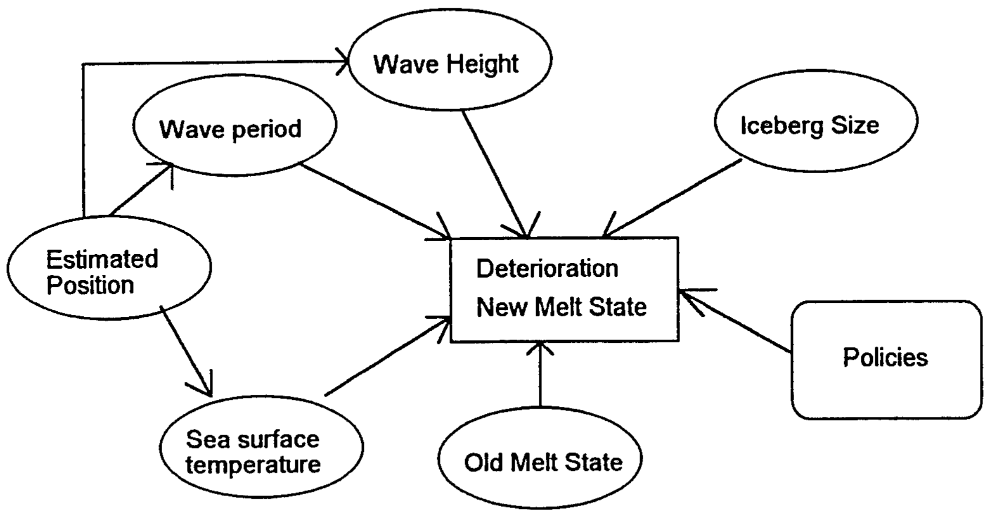


Figure 7. IIP Deterioration Model Influence Diagram.

Computation of Uncertainty.

The preceding development describes a comprehensive approach for characterizing the elements contributing to uncertainty in this very complex operational system. Recall that an objective of this analysis is to be able to estimate the probability that there will be no icebergs outside of the LAKI. It should be clear than an overall analytical model is not feasible for this system. Analytical relationships simply do not exist in many cases to link the various parts of the model. Lacking the capability to construct an analytical model, the only feasible approach is to develop a simulation model to represent the system. As noted above, a simulation model is descriptive and does not optimize parameter settings. However, careful selection of parameter settings can be used to evaluate those which are most promising. In conducting the analysis of the iceberg deterioration model, Armacost (1995b) used a sensitivity analysis approach to examine the model output sensitivity to errors in the input parameters. However, it was necessary to use a Monte Carlo simulation using probability distributions for the parameters to evaluate the effects of iceberg size on deletion policies.

At this point, it is clear that a simulation approach is the correct way to proceed. It is expected that the existing "What-If" model at IIP would be the appropriate vehicle for conducting the simulation. The What-If model would require modification to accommodate random variates in the simulation. A significant challenge is in the design of the experiment, given the potentially large number of factors. Creative use of robust design procedures would be an essential part of this effort.

Non-Computational Insights to Reduce Uncertainty.

Developing the above structure and examining the various submodels may lead to insights that will reduce output uncertainty without significant computational requirements. In this analysis, minimizing the probability that an iceberg occurs outside of the LAKI was established as the objective. Consider the example in Figure 8.

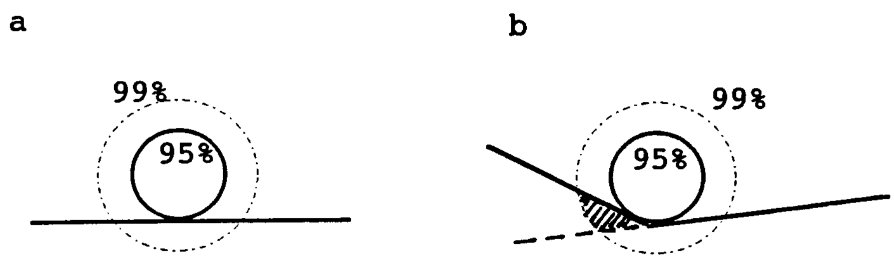


Figure 8. Limit Setting Icebergs and Construction of LAKI.

Figure 8 represents the 95% and 99% error circles for limit setting icebergs. Figure 8a illustrates constructing the LAKI tangent to the 95% error circle. The area below the LAKI represents the probability that the particular iceberg will actually be outside of the LAKI. Figure 8b also constructs the LAKI tangent to the 95% error circle, but now the iceberg is used as a corner point. Notice that the probability that the iceberg will actually be outside of the LAKI is larger than in case a (simply compare the area in the annular region between the 95% and 99% error circles that is outside of the LAKI.) This simple analysis should lead to a policy that states that one should not use limit setting icebergs as corner points in constructing the LAKI.

SUMMARY AND CONCLUSIONS

Risk requires a measure of damage and a measure of uncertainty. Damage is typically associated with the occurrence of the uncertain events. For the IIP, the undesirable event is encountering an iceberg outside of the limits of all known ice. Damage can range from a loss of credibility for the IIP to severe physical and environmental damage as well as loss of life if a vessel strikes an iceberg. A risk analysis depends on an uncertainty analysis which propagates the uncertainty in input elements (iceberg detection/classification, environmental factors, drift and deterioration models, resighting procedures, and numerous policies) to characterize the uncertainty in the output (the location of the LAKI). This analysis developed a comprehensive modeling approach for conducting such a risk analysis. Based on the sensitivity analyses of the drift and deterioration models, it is clear that an analytical representation for output uncertainty as a function of input uncertainty is not feasible. Instead, a promising approach is the use of Monte Carlo simulation utilizing the "What-If" DMPS model at IIP.

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